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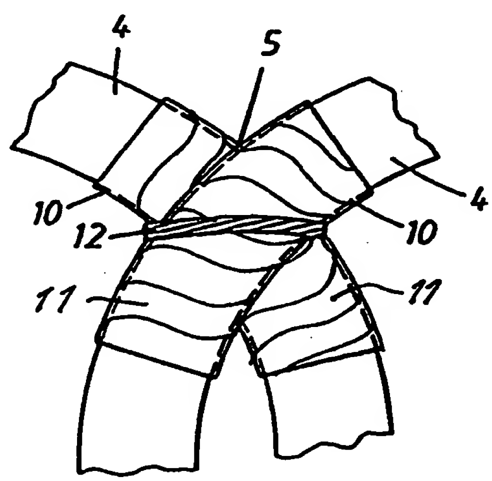
(57) Abstract

A device for avoiding wear between cables in the coil-end package of the stator (1) in a rotating electric machine comprises a resilient layer (10) arranged in the contact area (5) between two cables (4). The layer (10) permits a certain amount of relative movement between the cables (4) through shearing in the resilient material. The layer is formed by a sleeve (10) in which each cable (4) is encased in the contact area (5). The cable consists of a high-voltage cable (4). The sleeve (10) is formed by a helically shaped tape (11) of electrically insulating or conducting material.



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A ROTATING ELECTRIC MACHINE

The present invention refers to rotating electric machines such as synchronous machines, as well as dual-fed machines, applications in asynchronous static current converter cascades, outerpole machines and synchronous flow machines. The invention relates to such a machine according to the preamble of claim 1. The machine is provided with a device for avoiding wear between conductors in the coil-end package of the stator in the machine. The machine according to the invention is intended for use with high voltages, by which is meant electric voltages in excess of 10 kV. A typical working range for the device according to the invention may be of 36 kV-800 kV.

The problem addressed by the invention has arisen in connection with high-voltage electric alternating current machines, in the first place intended as generator in a power station for generating electric power. Such machines have conventionally been designed for voltages in the range 15-30 kV, and 30 kV has normally been considered to be an upper limit. This generally means that a generator must be connected to the power network via a transformer which steps up the voltage to the level of the power network, i.e. in the range of approximately 130-400 kV.

In US-A 2,885,581 the problem is to prevent movements in the coil-ends when the magnetic forces increase with increasing machine-sizes. A rigid joint is accomplished by means of impregnation. In US-A 2,959,699 a layer of stiff material is formed around between overlapping parts of the coil-ends so that a cylinder of stiff ma-

terial is formed around the core to reduce the movements.

A conductor is known through US-A 5,036,165, in which the insulation is provided with an inner and an outer layer of semiconducting pyrolized glassfiber. It is also known to provide conductors in a dynamo-electric machine with such an insulation, as described in US-A 5,066,881 for instance, where a semiconducting pyrolized glassfiber layer is in contact with the two parallel rods forming the conductor, and the insulation in the stator slots is surrounded by an outer layer of semiconducting pyrolized glassfiber. The pyrolized glassfiber material is described as suitable since it retains its resistivity even after the impregnation treatment.

By using high-voltage insulated electric conductors, in the following termed cables, in the stator winding of the machine, with solid insulation similar to that used in cables for transmitting electric power (e.g. XLPE cables) the voltage of the machine can be increased to such levels that it can be connected directly to the power network without an intermediate transformer. The conventional transformer can thus be eliminated.

With these high-voltage electric machines problems also arise in that the cables have a tendency to vibrate, causing the large coil-end packages to vibrate in relation to each other at frequencies double the network frequency, i.e. 100 Hz in a power network with a network frequency of 50 Hz, and 120 Hz in a power network with a nominal network frequency of 60 Hz, and at amplitudes of approximately 0.1 mm. The cables, provided with an outer semiconducting layer by means of which

their potential in relation to the surroundings shall be defined, are thus easily damaged due to wear against adjacent cables in the coil-end package.

The object of the present invention is to solve the above mentioned problem, and this is achieved by the machine described in the preamble of claim 1 being given the features specified in the characterizing portion of claim 1. This solution means that the cables are secured relative eah other permitting a relative movement in which the cables are not rubbing against each other

The invention is in the first place intended for use with a high-voltage cable of the type built up of a core composed of a number of strand parts, a semiconducting layer surrounding the core, an insulating layer surrounding the inner semiconducting layer, and an outer semiconducting layer surrounding the insulating layer, and its advantages are particularly prominent here. The invention refers particularly to such a cable having a diameter within the interval 20-200 mm and a conducting area within the interval 80-3000 mm^2. Such applications of the invention thus constitute preferred embodiments thereof.

In the machine according to the invention the windings are preferably of a type corresponding to cables with solid, extruded insulation, such as those now used for power distribution, e.g. XLPE-cables or cables with EPR-insulation. Such a cable comprises an inner conductor composed of one or more strand parts, an inner semiconducting layer surrounding the conductor, a solid insulating layer surrounding this and an outer semiconducting layer surrounding the insulating layer. Such cables are flexible, which is an important property in

this context since the technology for the device according to the invention is based primarily on winding systems in which the winding is formed from cable which is bent during assembly. The flexibility of a XLPE-cable normally corresponds to a radius of curvature of approximately 20 cm for a cable 30 mm in diameter, and a radius of curvature of approximately 65 cm for a cable 80 mm in diameter. In the present application the term "flexible" is used to indicate that the winding is flexible down to a radius of curvature in the order of four times the cable diameter, preferably eight to twelve times the cable diameter.

The winding should be constructed to retain its properties even when it is bent and when it is subjected to thermal stress during operation. It is vital that the layers retain their adhesion to each other in this context. The material properties of the layers are decisive here, particularly their elasticity and relative coefficients of thermal expansion. In a XLPE-cable, for instance, the insulating layer consists of cross-linked, low-density polyethylene, and the semiconducting layers consist of polyethylene with soot and metal particles mixed in. Changes in volume as a result of temperature fluctuations are completely absorbed as changes in radius in the cable and, thanks to the comparatively slight difference between the coefficients of thermal expansion in the layers in relation to the elasticity of these materials, the radial expansion can take place without the adhesion between the layers being lost.

The material combinations stated above should be considered only as examples. Other combinations fulfilling the conditions specified and also the condition of being semiconducting, i.e. having resistivity within

the range of 10^{-1}-10^{6} ohm-cm, e.g. 1-500 ohm-cm, or 10-200 ohm-cm, naturally also fall within the scope of the invention.

The insulating layer may consist, for example, of a solid thermoplastic material such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl pentene (PMP), cross-linked materials such as cross-linked polyethylene (XLPE), or rubber such as ethylene propylene rubber (EPR) or silicon rubber.

The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed in.

The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed in or not - at least in the proportions required to achieve the conductivity necessary according to the invention. The insulating layer and the semiconducting layers thus have substantially the same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymers/nitrile rubber, butyl graft polyethylene, ethylene-butyl-acrylate-copolymers and ethylene-ethyl-acrylate copolymers may also constitute suitable polymers for the semiconducting layers.

Even when different types of material are used as base in the various layers, it is desirable for their coefficients of thermal expansion to be substantially the same. This is the case with combination of the materials listed above.

The materials listed above have relatively good elasticity, with an E-modulus of E<500 MPa, preferably <200 MPa.

The elasticity is sufficient for any minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction of the elasticity so that no cracks appear, or any other damage, and so that the layers are not released from each other. The material in the layers is elastic, and the adhesion between the layers is at least of the same magnitude as the weakest of the materials.

The conductivity of the two semiconducting layers is sufficient to substantially equalize the potential along each layer. The conductivity of the outer semiconducting layer is sufficiently large to enclose the electrical field in the cable, but sufficiently small not to give rise to significant losses due to currents induced in the longitudinal direction of the layer.

Thus, each of the two semiconducting layers essentially constitutes one equipotential surface and the winding, with these layers, will substantially enclose the electrical field within it.

There is, of course, nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

The invention will now be described in more detail with reference to the accompanying drawings in which:

Figure 1 shows a view in perspective of a part of the coil-end package at one end of the stator in an electric alternating current generator,

Figure 2 shows a cross section through a cable of the type used in the stator winding,

Figure 3 shows a cross section through a cable in the coil-end package incorporating a device according to the invention,

Figure 4 shows the contact area between two cables in the coil-end package, and

Figure 5 shows the manufacture of a device according to the invention.

Figure 1 illustrates a section of the coil-end package in an alternating current generator. With its inner vertical surface 2, the stator 1 surrounds the rotor of the generator with an air gap. Cables 4 forming the winding protrude in an arc from one slot in the upper surface 3 of the stator 1 and enter another slot in the stator. These arcs of cables or coils form coil ends which come into contact with each other. One such contact point is designated 5 in Figure 1.

The arc-shaped coil ends become relatively loose and slippery and the vibration level reached by the cables during operation at a frequency of approximately 100 Hz causes relative movement between the cables in the contact area, a relative movement with an amplitude of approximately 0.1 mm. Such movement would cause damaging wear between the cables which in this case have no sheath.

Figure 2 shows a cross section through a cable 4 which is used in conjunction with the present invention. The cable 4 consists of a core 6 composed of a number of strand parts made of copper, for instance, and having circular cross section. This conductor 6 is arranged

in the middle of the cable 4. Around the conductor 6 is a first semiconducting layer 7. Around the first semiconducting layer 7 is an insulating layer 8, e.g. XLPE-insulation, and around the insulating layer 8 is a second semiconducting layer 9. In this context, therefore, a cable does not include the outer protective sheath that normally surrounds a cable for power distribution. The cable may be of the size specified in the introduction.

Figure 3 shows a cross section through such a cable, incorporating a device according to the invention. To avoid wear in the contact areas between the cables, the cables must be secured in relation to each other while permitting a relative movement that does not entail the cables rubbing against each other and thereby becoming worn. The cables 4 are therefore provided with a sleeve 10 in the contacts.

The sleeve 10 consists of a helically shaped wound tape 11 (Fig. 4). The material in the sleeve 10 is not limited to any specific material but may be any type of material with a certain elasticity. Neither need the material be electrically insulating. It may be electrically conducting, although the former may be preferable in certain machine designs.

Figure 4 shows how the cables are secured to each other at the contact point 5 by means of a securing device in the form of a bundle binder 12. It is also advisable for the cables 4 to be similarly secured and clad in resilient material at outer fixed points in the stator as well.

Figure 5 shows a suitable method of producing the tape 11 which is to form the sleeve 10 on the cables. A work piece 13 in the form of a tube or hose of material

suitable for the purpose is slit along a helical line 14. A helically shaped tape 11 is thus formed to produce the sleeve 10 to cover the cable 4 in the contact area 5. Contrary to a normal, straight tape wound around the cable, the helically shaped tape is held in place by itself. No binder is therefore required, which would make the coil-end package thicker.

Using this method, tape can easily be produced which, despite being relatively thick, can easily be given the necessary helical shape. The layer in the sleeve 10 must be sufficiently thick to permit relative movement between the cables through shearing in the material, without slipping between the surfaces. The thickness of the layer may vary between 0.5 and 5 mm depending on the cable diameter which may vary between 10 and 150 mm. The device according to the invention prevents wear on the cables which would rapidly damage the outer semiconductor on the XLPE insulation.

CLAIMS

1. A rotating electric machine comprising a stator (1) with a winding, **characterized** in that the winding consists of a high-voltage cable (4), comprising an insulating layer (8) covered by a semi-conducting layer (9) and in that a device (10) for avoiding wear between adjacent cables (4) in a coil-end package of the winding is arranged in the winding, the device comprising a resilient layer (10), in contact with cables (4) so that the layer (10) permitsa relative movement between the cables through shearing in the resilient layer (10).

2. A rotating electric machine as claimed in claim 1, **characterized** in that said device (10) is formed by a sleeve (10) in which each cable (4) is encased in the contact area (5) between two cables (4).

3. A rotating electric machine as claimed in claim 2, **characterized** in that the sleeve (10) consists of a heically shaped tape (11) of an elastic material.

4. A rotating electric machine as claimed in claim 3, **characterized** in that the helically shaped tape (11) is formed by slitting a hose or tube (13) along a helical line (14).

5. A rotating electric machine as claimed in claim 3 or 4 , **characterized** in that said elastic material is electrically insulating.

6. A rotating electric machine as claimed in claim 3 or 4, **characterized** in that said elastic material is electrically conducting.

7. A rotating electric machine as claimed in any of claims 1-6, **characterized** in that the high-voltage cable (4) is composed of a core (6) having a number of strand parts, a semiconducting layer (7) surrounding the core (6), an insulating layer (8) surrounding the inner semiconducting layer, and an outer semiconducting layer (9) surrounding the insulating layer.

8. A rotating electric machine as claimed in claim 7, **characterized** in that the high-voltage cable (4) has a diameter within the interval 20-200 mm and a conducting area within the interval 80-3000 mm^2.

9. A rotating electric machine as claimed in claim 8, **characterized** in that the winding is flexible and that said layers adhere to each other.

10. A rotating electric machine as claimed in claim 9, **characterized** in that said layers of material consist of materials with such elasticity and such a relation between the coefficients of thermal expansion that the changes in volume in the layers caused by temperature fluctuations are absorbed by the elasticity of the materials so that the layers retain their adhesion to each other at the temperature fluctuations occurring during operation.

11. A rotating electric machine as claimed in claim 9 or claim 10, **characterized** in that the materials in said layers have high elasticity, preferably with an E-modulus less than 500 MPa, most preferably less than 200 MPa.

12. A rotating electric machine as claimed in any of claims 9-11, **characterized** in that the coefficients of thermal expansion for the materials in said layers are of substantially the same magnitude.

13. A rotating electric machine as claimed in any of claims 9-12, **characterized** in that the adhesion between the layers is of at least the same magnitude as in the weakest of the materials.

14. A rotating electric machine as claimed in any of claims 9-13, **characterized** in that each of the semiconducting layers essentially constitutes one equipotential surface.

Fig-1

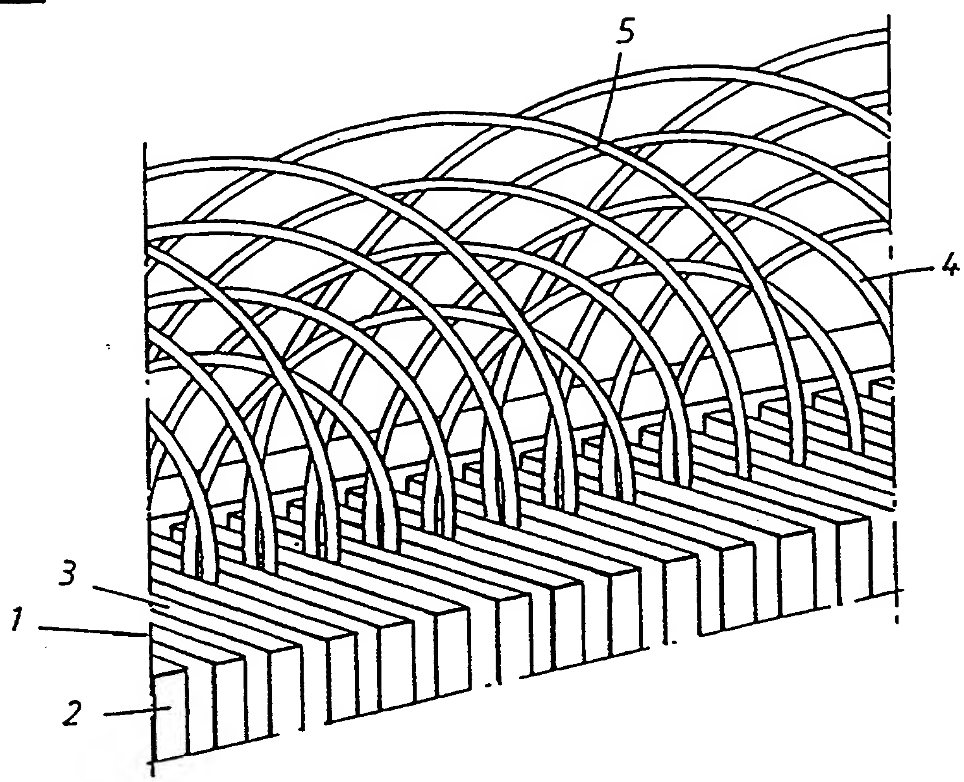

Fig-2

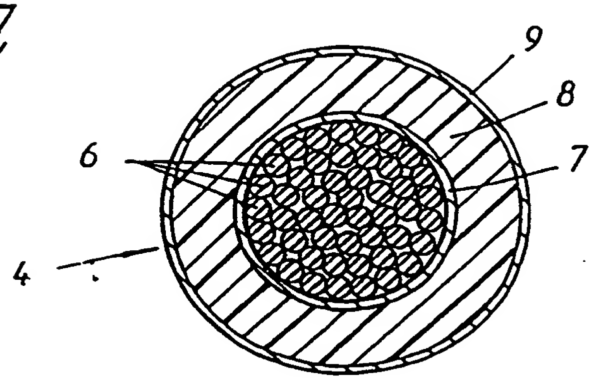

Fig. 3

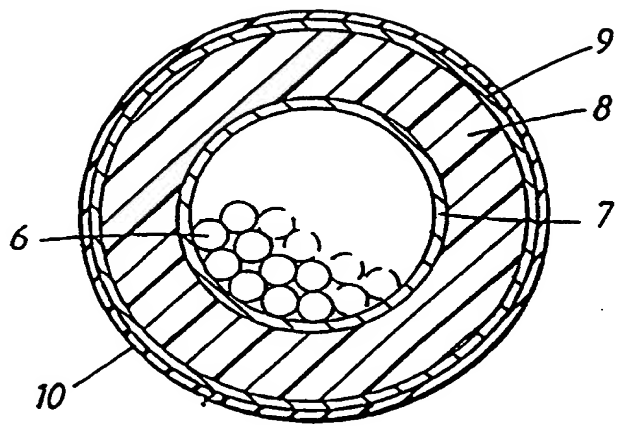

Fig. 4

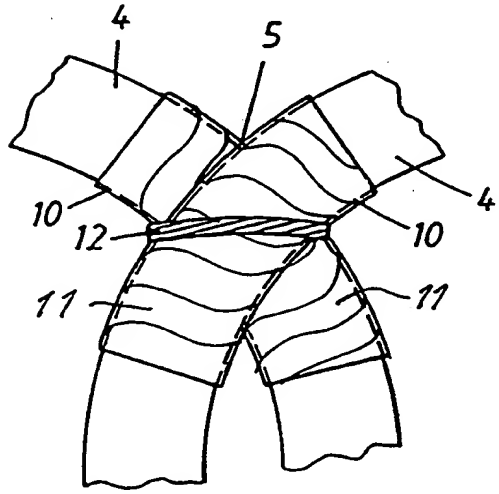

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Fig. 5